ROLLER-TRANSDUCER SCANNING OF WOODEN PALLET PARTS FOR DEFECT DETECTION

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Abstract. Ultrasonic scanning experiments were conducted on two species of pallet deckboards using rolling transducers in a pitch-catch arrangement. Sound and unsound knots, cross grain, bark pockets, holes, splits, decay, and wane were characterized using several ultrasound parameters. Almost all parameters displayed sensitivity to defects distinctly from clear wood regions—being greatest for unsound knots, bark pockets, decay, holes, splits, and less for sound knots and cross grain. This study supports our conjecture that on-line inspection of wooden pallet parts is possible using rolling-transducer ultrasonic inspection.

INTRODUCTION

During the last few years, many researchers have investigated the possibility of the defect detection and grading of wooden materials using ultrasonic technology [1-9]. Their studies have included both naturally occurring, as well as processing related, wood defects and have tested laboratory sample or surfaced lumber. Most of this work was carried out using ultrasonic waveform parameters such as time of flight (TOF) or propagation velocity measurements for the detection of defects. The basis of these studies is that the defects in wood changes ultrasonic signal propagation. Simple ultrasonic propagation velocity, however, may not be sufficient to characterize all types of wood defects. Some defect types may not affect velocity, but may impact other ultrasonic parameters, e.g. peak amplitude, time to peak amplitude, centroid time, root mean square of the time domain, pulse length, insertion loss, frequency domain mode, frequency domain energy, etc. Recent reports by Halabe et al. [10-12] showed that frequency domain analysis provides valuable information for detecting defects in wood.

In the United States, 30-40% of the sawn hardwoods produced annually go into the manufacture of wooden pallets [13]. Each year, over 400 million new wooden pallets are constructed, consuming 4.5 billion board feet of hardwood lumber [14]. Typically, wooden pallets consists of two parts—stringers, the structural center members that support the load and deckboards, the top and bottom members that provide the dimensional stability and

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products placement. Usually, pallet parts are produced from solid wood (lumber) or from the center cant material of logs. These cants have a high percentage of defects and have less market value for other solid wood products.

The most common defects in wooden pallet parts are knots, cross grain, bark pockets, holes, splits, decay, shake, and wane. The extent and severity of these defects often depend on wood species. High quality pallet parts produce high-grade pallets with a longer life cycle, which promotes multiple trips per pallet. Manual grading and sorting of pallet parts is a slow and inaccurate process, which depends on the individual skill of the grader. Furthermore, the presence, location, extent of defects in pallet parts are often difficult to ascertain accurately, making the grading system complicated. An automated inspection system can be very useful for detecting defects and sorting of these pallet parts. An economic analysis by Schmoldt et al. [15] has demonstrated profit potential. Recently, research has been conducted to develop an automated pallet part inspection system [16-20].

The present study investigates the possibility of on-line inspection of wooden pallet parts by ultrasonic scanning using rolling transducers and examines a variety of ultrasonic parameters. Scanning data were collected for two species of wooden pallet parts. Several ultrasonic parameters were measured for each defect type. Experimental methods and results of those tests are described below.

MATERIALS AND METHODS

Scanning Equipment

The ultrasonic scanning apparatus was designed by the Ultrasonic Technology Group, Forest Products Division of Perceptron Inc. It consists of in-fed and out-fed roll beds, two pinch rollers for part movement, and two rolling transducers which are mounted in an ultrasonic scanning ring. The necessary electronics and software to control material movement, signal generation, data collection and analysis were supplied by Perceptron. Pallet part samples (obtained from a local manufacturer) move through the system lying on a face and ultrasonic signal propagates through the board thickness. Data are collected, stored, and processed by Lab View™ software modules. Different ultrasonic parameters can be plotted against the board length for single line scanning. The desired resolution (number of waveform per inch) can be achieved by controlling roller speed and the number of pulses generated and received per second.

Ultrasonic Parameters

The most important parameters rely on the energy in the received signal. Wave energy is expressed as the time integral of the voltage v squared:

$$E = \int v^2(t)\,dt. \tag{1}$$

The energy value (EV) is derived from the energy E and is expressed as the ratio of the energy received by the receiving transducer to the energy input to the transmitting transducer. This parameter is normally expressed in decibels (dB) and by convention on a logarithmic scale (and hence a negative number) with lower signal ratios (containing less energy) being more negative.

The pulse length parameter (PL) is simply the time for which the pulse is "on," and depends upon the transmitted ultrasound frequency. This is defined as 1.25 times the time required for the received wave energy to rise from 10% to 90% of its total energy and is expressed in microseconds. The energy value and pulse length can be combined into a single parameter, known as energy/pulse value (EPV) to provide more defect resolution. Time of flight (TOF) measurement can be associated with the energy, amplitude, or centroid of the signal. TOF-energy is the time required for the energy to reach its threshold value, as a percentage of the maximum value. For instance, if the threshold value is 40%, then TOF-energy is simply the time at which the integral value reaches 40% of the total energy value.

Data Collection

Twenty fresh-cut and unplaned deckboards were collected for both yellow-poplar and red oak species from a pallet manufacturer. The boards were place immediately in cold storage to reduce their drying rate. A line was mark on each board through a defect of interest and scanning was performed along the line through specimen's thickness from face to face. Boards were scanned with two scanning rates—10 waveforms/inch (70ft/m roller speed) and 4 waveforms/inch (220 ft/m roller speed). Measurements were carried out at 120 kHz transmitting frequency and 500 kHz sampling frequency.

RESULTS AND DISCUSSION

The ultrasonic parameters—energy, pulse length (PL), time of flight-centroid (TOF-centroid), time of flight-energy (TOF-energy), time of flight-amplitude (TOF-amplitude), energy value (EV), and energy/pulse value (EPV)—were measured for each of the defects. Typical results for signal propagation through sound knots of yellow-poplar deckboards are shown in Figure 1.

TOF-centroid increases in the region of the sound knot. The energy of the received signal decreases to near zero through sound knots. The parameters EV and EPV also decrease considerably, as the energy vanishes. The effects of unsound knots on the ultrasonic parameters are shown in Figure 2. Both PL and TOF-centroid were found to increase sharply with unsound knot and exhibited a higher value than sound knots The

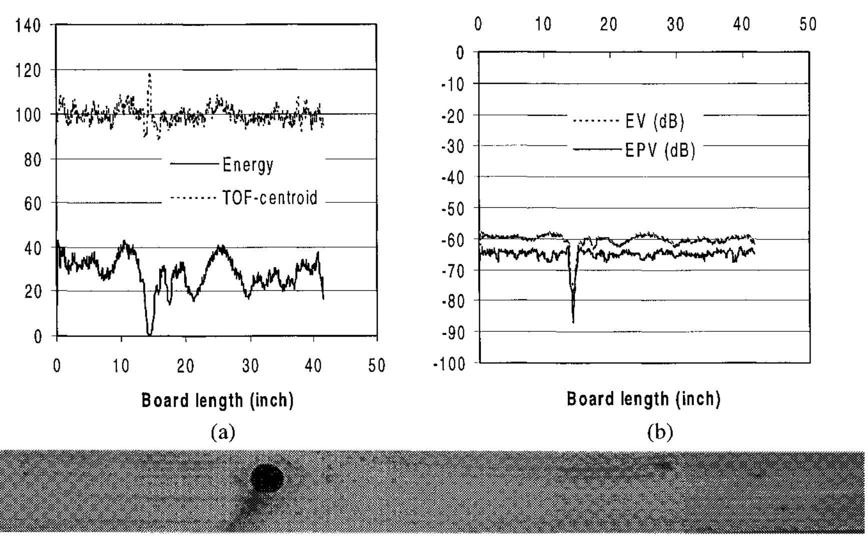

Figure 1. Ultrasonic measurements through a sound knot for yellow-poplar deckboard, (a) energy and time of flight-centroid, (b) energy value and energy/pulse value.

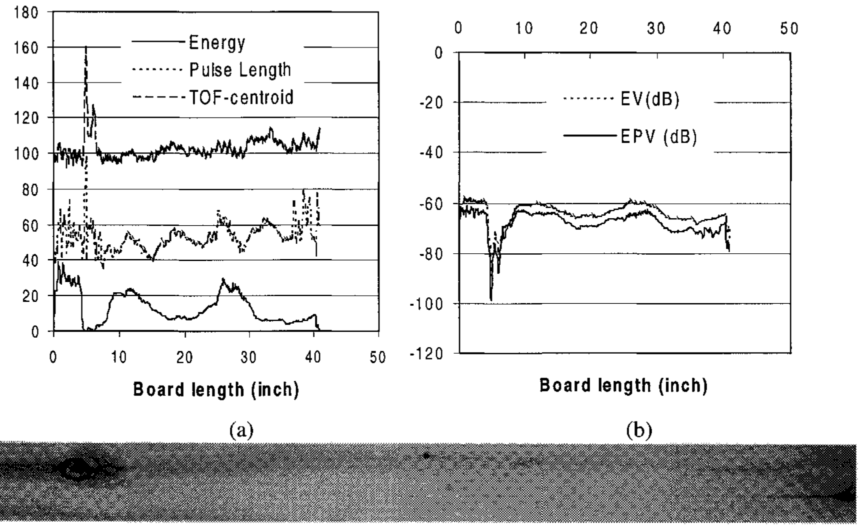

Figure 2. The effect of an unsound knot on ultrasonic parameters for a yellow-poplar deckboard, (a) energy, pulse length, and time of flight-centroid, (b) energy value and energy/pulse value.

responses of EV and EPV to unsound knots are similar to sound knot but more negative (higher loss). These differences in parameter values between sound and unsound knots can be used to help distinguish them.

Figure 3 shows results for a hole on a yellow-poplar deckboard. The hole can easily be detected by observing a tremendous rise in PL and TOF-centroid and very negative values for EV and EPV. Decayed wood in an oak deckboard can be distinguished from clear wood in a similar way, as shown in Figure 4. Assessing defect size is also possible as parameters are plotted against board length. Typically, decay has a similar ultrasonic signature as unsound knots because unsound knots contain some decayed wood.

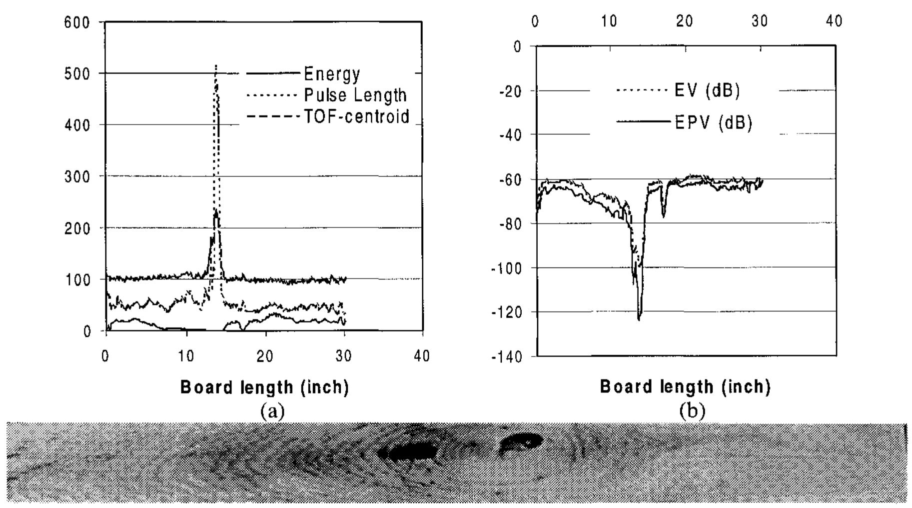

Figure 3. Scanning results through a hole on a yellow-poplar deckboard, (a) energy, pulse length, and time of flight-centroid, (b) energy value and energy/pulse value.

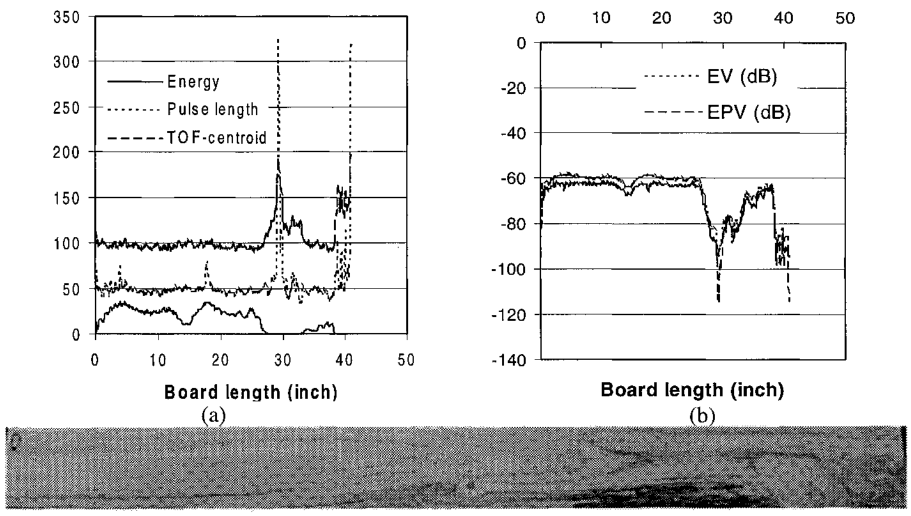

Figure 4. Measured ultrasonic parameters through decay for red oak.

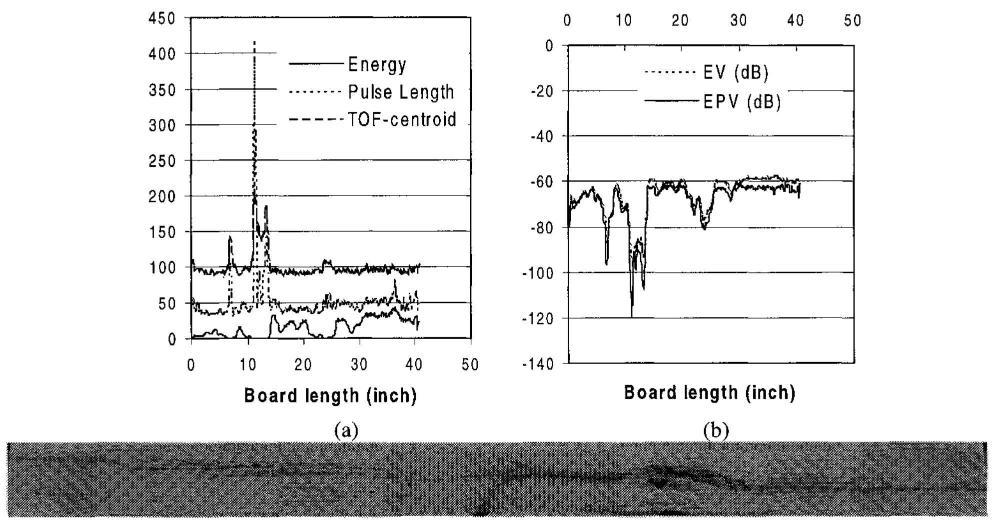

Figure 5. Results of ultrasonic measurements through a split in red oak, (a) energy, pulse length, and time of flight-centroid, (b) energy value and energy/pulse value.

Ultrasonic parameters are sensitive to splits and bark pockets as presented in Figures 5 and 6, respectively. The responses of these ultrasonic parameters to bark pockets, splits, decay, holes, and unsound knots are very similar, although there are some value differences between the defects.

Several tests of equipment repeatability and reliability were also conducted. Figure 7(a) compares energy/pulse values obtained using two different scanning rates—10 waveforms/inch and 4 waveforms/inch. It can be observed from this figure that scanning rate has little effect on ultrasonic measurements. To examine the repeatability of data collection, boards were scanned ten times and the coefficient of variation (CV%) was

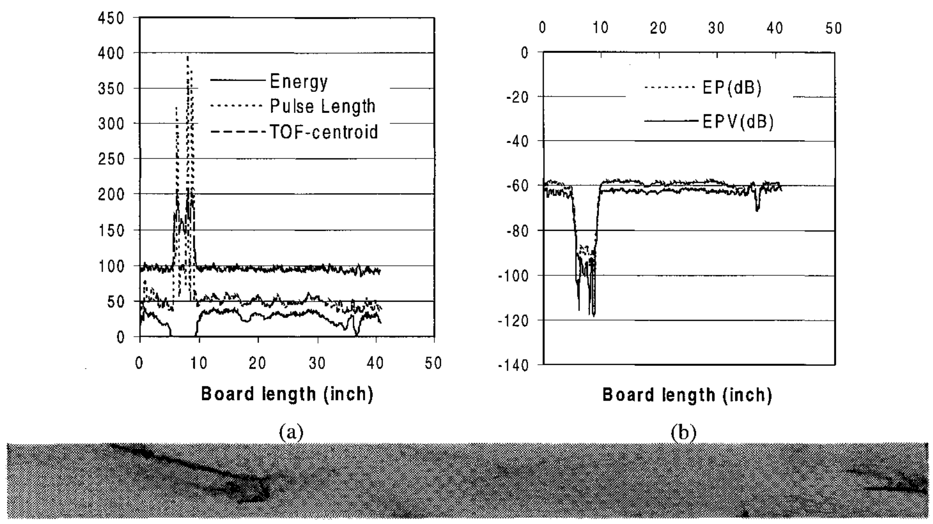

Figure 6. The effect of a bark pocket on the ultrasonic measurements for red oak.

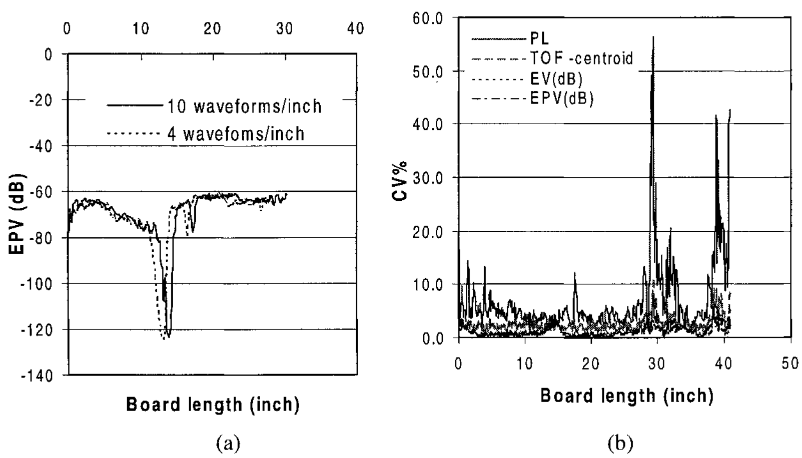

Figure 7. A comparison of the effect of different scanning rates on energy/pulse value measurements (a) and coefficients of variation (CV%) for ten repeated measurements of several different parameters (b).

calculated for several parameters. The calculated coefficients for a decayed oak board are presented in Figure 7(b). A low CV% for most of the parameters suggested that the data collection repeatability is good.

CONCLUSIONS

On-line detection of defects in oak and yellow-poplar deckboards appears feasible using ultrasonic measurements and rolling transducers. Most of the ultrasonic parameters were sensitive to unsound knots, bark pockets, decay, holes, splits, and wane. Typically, pulse length and time of flight increased sharply for those defects, whereas higher energy losses also occurred. Energy value and energy/pulse value were found to be the most sensitive parameters for detecting defects. These ultrasonic measurements appear to be less sensitive to sound knots. The low coefficients of variation and well-matched measurements at different scanning speeds indicate that repeatability and reliability of this type of data collection are quite acceptable.

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